SCIENCE WRITERS' GUIDE TO TERRA

Terra Science Objectives

The launch of NASA's Terra spacecraft marks a new era of comprehensive monitoring of the Earth's atmosphere, oceans, and continents from a single space-based platform. Data from the five Terra instruments will create continuous, long-term records of the state of the land, oceans, and atmosphere. Together with data from other satellite systems launched by NASA and other countries, Terra will inaugurate a new self-consistent data record that will be gathered over the next 15 years.

The science objectives of NASA's Earth Observing System (EOS) program are to provide global observations and scientific understanding of land cover change and global productivity, climate variability and change, natural hazards, and atmospheric ozone. Observations by the Terra instruments will:

- provide the first global and seasonal measurements of the Earth system, including such critical functions as biological productivity of the land and oceans, snow and ice, surface temperature, clouds, water vapor, and land cover;

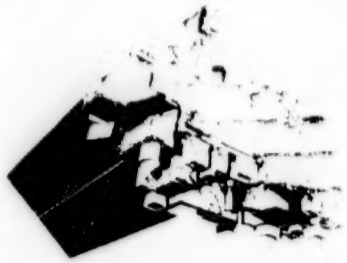
- improve our ability to detect human impacts on the Earth system and climate, identify the "fingerprint" of human activity on climate, and predict climate change by using the new global observations in climate models;

- help develop technologies for disaster prediction, characterization, and risk reduction from wildfires, volcanoes, floods, and droughts, and

- start long-term monitoring of global climate change and environmental change.

From an altitude of 438 miles (705 km), Terra will circle the Earth 16 times a day from pole to pole (98 degree inclination), crossing the equator at 10:30 a.m. The five Terra instruments will operate by measuring sunlight reflected by the Earth and heat emitted by the Earth. This "radiant energy" is collected by the instruments and focused onto specially designed detectors that are sensitive to selected regions of the electromagnetic spectrum, ranging from visible light to thermal infrared. The information produced by these detectors is transmitted back to Earth and processed by computers into data and images.

Advanced Spaceborne Thermal Emission and Reflection Radiometer. ASTER will provide the highest resolution images (15-90 m) of the Terra instruments. Images can be obtained in visible, near-infrared, shortwave-infrared, and thermal infrared wavelengths. ASTER consists of three separate telescope systems, each of which can be pointed by investigators at selected targets. By pointing to the same target twice,



ASTER can acquire high-resolution stereo images. The instrument operates for a limited time during each orbit.

Clouds and the Earth's Radiant Energy System. CERES consists of two broad-band scanning radiometers that measure reflected sunlight, Earth-emitted thermal radiation, and total radiation. The CERES scanners operate continuously throughout the day and night portion of an orbit. The two instruments obtain a complete representation of radiation from any direction by sampling at multiple angles the reflected and emitted radiation.

Moderate-Resolution Imaging Spectroradiometer. MODIS will observe the entire surface of the Earth every 1-2 days with a whisk-broom scanning imaging radiometer. Its wide field of view (over 2300 km) will provide images of daylight-reflected solar radiation and day/night thermal emissions over the entire globe. MODIS will be able to see features as small as 250 m-1 km. Some of the 36 different wavelength regions that MODIS samples have never before been monitored from space. MODIS operates continuously.

Measurements of Pollution in the Troposphere. MOPITT is a scanning radiometer designed to measure for the first time from space carbon monoxide and methane concentrations in the lower atmosphere. The instrument operates continuously and is capable of providing science data on both the day and night portions of an orbit.

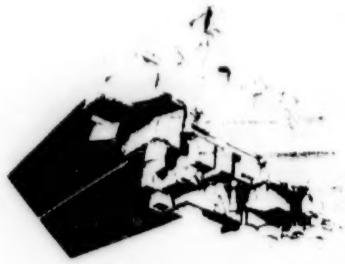
Multi-Angle Imaging Spectroradiometer. MISR is a new type of instrument designed to view the Earth with cameras pointed at nine different angles. As the instrument flies overhead, the Earth's surface is successively imaged by all nine cameras, each in four wavelengths. Global coverage is acquired about once every 9 days. MISR operates only during the daylight portion of an orbit.

Data from the five Terra instruments will be used to produce dozens of data products on different aspects of the Earth system. Some of these geophysical data sets will be produced using data from more than one instrument. For example, aerosol properties will be measured by MODIS using its wide spectral range and 1-2 day single view coverage, and also independently by MISR using its multi-angle data, narrower spectral range, and 2-9 day coverage.

These simultaneous, carefully registered data products will allow the EOS instrument teams to develop broad science approaches to specific problems. For instance, in the case of deforestation resulting from biomass burning, fires and emitted smoke particles will be observed by MISR and MODIS, deforestation and burn scars will be observed by ASTER and MODIS, emitted trace gases (carbon monoxide and methane) will be measured by MOPITT, and the radiative forcing of climate will be observed by CERES.

What Terra Will Measure

Region	Measurement	Instrument(s) Used
Atmosphere	Cloud Properties	MODIS, MISR, ASTER
	Radiative Energy Fluxes	CERES, MODIS, MISR
	Tropospheric Chemistry	MOPITT
	Aerosol Properties	MISR, MODIS
	Atmospheric Temperature	MODIS
	Atmospheric Humidity	MODIS
Land	Land Cover and Land Use Change	MODIS, MISR, ASTER
	Vegetation Dynamics	MODIS, MISR, ASTER
	Surface Temperature	MODIS, ASTER
	Fire Occurrence	MODIS, ASTER
	Volcanic Effects	MODIS, MISR, ASTER
Ocean	Surface Temperature	MODIS
	Phytoplankton and Dissolved Organic Matter	MODIS, MISR
Cryosphere	Land Ice Change	ASTER
	Sea Ice	MODIS, ASTER
	Snow Cover	MODIS, ASTER



Terra Research Profiles

Data from Terra will be used by researchers worldwide on a broad range of scientific problems. This section profiles just a few highlights of those anticipated research projects.

Land Cover Changes

Cutting down forests and turning prairie into farmland affect the Earth's climate. Trees and vegetation absorb carbon dioxide from the atmosphere, while decomposition of organic material returns carbon dioxide to the atmosphere. Knowing how much vegetation is being destroyed, how much is growing back, and what happens to the organic litter is critical to understanding the effects of human land use on climate.

Scientists monitored burning in the tropics with data from National Oceanic and Atmospheric Administration (NOAA) weather satellites and from the Earth Probe Total Ozone Mapping Spectrometer (TOMS). MODIS is the first satellite sensor that will take a global daily inventory of human-induced land cover change.

Inez Fung, an atmospheric scientist at the University of California, Berkeley, will use MODIS to monitor burning forests in the Amazon, Southeast Asia, and Africa. Burning is generally concentrated in small areas that would be impossible to see without satellites. Burning of trees and organic material pumps carbon dioxide, carbon monoxide, methane, and aerosols into the atmosphere. MODIS can also be used to monitor how well plants and trees recover after a fire and distinguish farmland from forest and old-growth forests from regrowing grasslands.

Jonathan Foley, a climatologist at the University of Wisconsin-Madison, studies how sweeping landscape changes influence both regional and global climate. For example, over the past three centuries humans worldwide have cultivated nearly 18 million square kilometers of land, an area roughly the size of South America. This massive transformation of land, along with deforestation in both tropical and temperate regions, is little studied and could have a significant influence on climate.

Foley will use MODIS data to measure how land cover change affects local climates, such as those in the Amazon, and how changes in land cover affect soil moisture and patterns of flooding. He will also study changes in global carbon storage, a critical factor in the climate equation as forests, which store carbon, are cut down and their stored carbon is released to the atmosphere.

Tracking Air Pollution

Scientists understand much less about what happens to pollution in the lower part of the atmosphere, called the troposphere, than in the higher stratosphere. The ever-changing troposphere with its clouds and weather is much more complex. There have been very few satellite observations of chemicals in the lowest 10 miles of the atmosphere.

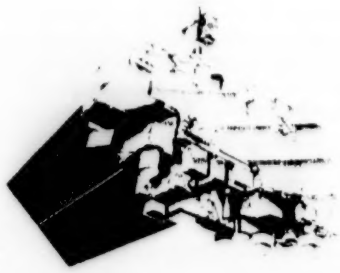
MOPITT will provide the first global maps of some important gases in the troposphere and give scientists their first opportunity to explore atmospheric processes in this region on a global scale. Three-dimensional maps of carbon monoxide concentrations will be produced, which will be updated every six hours or so, much like a weather forecast. These maps will be used to follow plumes of pollution around the globe, study how long pollutants survive in the atmosphere, and determine how far they travel from their source.

Carbon monoxide, produced primarily by combustion processes such as fossil fuel burning and biomass burning, is generally present in the atmosphere at low concentrations – just one molecule in 10 million. But concentrations vary considerably across the Earth, by a factor of three or more. MOPITT will use sensitive instrumentation to measure how much radiation is absorbed by carbon monoxide at three or four different altitudes within the troposphere, said John Gille at the National Center for Atmospheric Research.

Existing carbon monoxide measurements come from ground-based networks, airplanes or balloons. These measurements have shown that even above relatively pristine regions such as the South Pacific, elevated levels of pollutants such as carbon monoxide and ozone exist. A predecessor of MOPITT, the Measurement of Air Pollution from Satellites instrument that flew on the space shuttle, provided snapshots of the global distribution of carbon monoxide.

To produce three-dimensional maps of carbon monoxide concentrations, atmospheric physicists Guy Brasseur at the National Center for Atmospheric Research and John McConnell at York University are working to combine the carbon monoxide concentration data with powerful atmospheric models. These maps will give scientists the first global pictures of how carbon monoxide varies over the seasons and at different regions and latitudes.

The maps will also provide the first global scenes of how plumes of pollution move around the globe. Atmospheric physicist Daniel Jacob of Harvard University plans to use these maps to identify carbon monoxide source regions and begin to answer questions about how pollution in China affects the United States.



Atmospheric chemist Prasad Kasibhatla of Duke University plans to use MOPITT data to assess how burning fossil fuels and biomass has affected the ability of the atmosphere to clean itself. Pollutants in the atmosphere can be removed naturally by chemical reactions with the hydroxyl radical (OH), a highly reactive molecular fragment consisting of a singular hydrogen atom bound to a single oxygen atom. Kasibhatla wants to determine how much hydroxyl radical there is and how this "cleansing agent" varies over time. Low concentrations and a short lifetime make the hydroxyl radical difficult to measure. By studying how carbon monoxide is destroyed in the troposphere, he will infer information about the hydroxyl radical.

Another pollutant formed by combustion processes is nitric oxide, which in combination with carbon monoxide, water vapor, and sunlight produces tropospheric ozone, a greenhouse gas that has been rising in concentration in the upper troposphere (5-10 miles high). As part of their modelling, McConnell and Brasseur plan to study tropospheric ozone production and seek explanations for its rise.

Piercing the Secrets of Clouds

Clouds play an important and surprisingly complex role in regulating the temperature at the Earth's surface. The net effect of clouds on a global scale is to cool the planet by reflecting solar radiation back into space before it can warm the atmosphere and the ground. But some clouds, such as the high, wispy cirrus clouds, are poor sunshields that instead trap radiation rising from the warmed Earth and prevent it from leaving the atmosphere. On balance – at least in our current climate – the Earth is cooler because of clouds.

But if clouds change as the result of a warmer climate, will their cooling capability diminish? Climate researchers agree that not enough is known about how clouds form and change to answer that question.

MODIS will map global cloud cover in greater detail than ever before – seeing features as small as 270 yards (250 meters) across compared to the best current satellite observations of more than 1000 yards (1 km) – and it will be able to pick out even thin, hard-to-see clouds. MODIS will also peer inside clouds to provide global measurements of the size of cloud droplets, a key property that determines how much radiation a cloud traps or scatters.

Atmospheric scientist Dennis Hartmann of the University of Washington plans to use MODIS to continue his research on a particular cloud type that plays a major role in the global temperature balance. Marine stratocumulus clouds are extensive, solid cloud layers that form in the subtropics off the west coasts of the major continents. As these clouds move toward the equator and warmer waters, they break up into small patches and their thickness changes, which alters their ability to shield solar radiation.

Scientists do not understand exactly why this transition from stratus to cumulus clouds takes place. Hartmann and his colleagues plan to use the fine-scale MODIS cloud data to study the question. The answer will help to improve the predictions of future climate change produced by climate models.

Paul Menzel of the National Oceanic and Atmospheric Administration's National Environmental Satellite, Data, and Information Service in Madison, Wis., will use MODIS data to study a very different type of cloud that acts to warm the atmosphere. Thin, patchy cirrus clouds, which form several miles high, are made of ice crystals instead of water droplets. These semi-transparent clouds are hard for satellites to see, especially over polar regions where they "disappear" against the snow-covered landscape. With MODIS cloud data Menzel will study what causes cirrus clouds to form and how their ice crystals trap radiation.

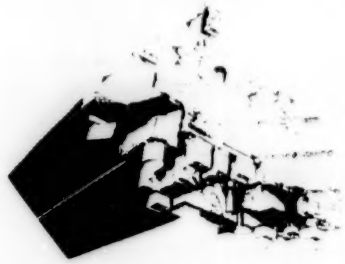
MODIS will produce the first highly detailed global maps of cirrus cloud cover, which will significantly improve the ability of scientists to track changes in the amount of cirrus over time. According to recent research, cirrus clouds – and their atmospheric warming influence – may be increasing over areas with heavy air traffic as the contrails produced by jet exhaust form cirrus clouds.

Ocean Temperature and Climate

Oceans are the heat engines driving the Earth's climate. Warm ocean currents travel from the equator toward the polar regions, warming the coldest portions of the globe. Scientists measure sea surface temperature using satellites to determine how climate change affects the ocean and how the oceans affect climate. Sea surface temperature maps also help scientists visualize the ocean's turbulent flow patterns, helping scientists study important ocean circulation systems like the Gulf Stream.

Climate researcher Timothy Liu of NASA's Jet Propulsion Laboratory will use MODIS sea surface temperature measurements to understand how the oceans interact with the atmosphere. Sea surface temperatures represent the amount of heat stored in the upper part of the ocean, which has a strong effect on climate because the atmosphere and the oceans are constantly exchanging heat. Liu will use MODIS sea surface temperature information to make better predictions about how the Earth's climate will change.

Changes in sea surface temperature patterns are also an indication of physical processes in the ocean, such as ocean fronts, eddies, and upwelling. Understanding these phenomena is like understanding weather patterns in the atmosphere. Peter Cornillon, an oceanographer at the University of Rhode Island, has used sea surface temperature data from NOAA satellites to explore ocean physical processes for 15



years. He will continue his research with MODIS data to look for long-term trends and examine how ocean circulation changes over years and decades.

Satellites can see sharp differences along boundaries, or fronts, between warm and cold masses of water. Between the warm Gulf Stream and the surrounding Atlantic Ocean, there is a well-defined front caused by a temperature difference of up to 18 degrees Fahrenheit (10 degrees Celsius). Another front lies along the edge of the continental shelf, where shallow, warmer waters become cool quickly as the depth of the seafloor rapidly increases. Fronts are important regions for biological activity in the ocean.

Fronts occur almost everywhere in the ocean, said Cornillon, but most are not as strong or well defined as the fronts along the continental shelf or the Gulf Stream. MODIS global ocean temperature data will allow for an unprecedented view of fronts in the world's oceans, he said.

Sea surface temperature measurements from MODIS will also help scientists trace the physical circulation of the ocean on a smaller scale, defining eddies and areas of upwelling. Upwelling happens when cold waters from the deep ocean flow upward to the surface. The deep cold waters are nutrient rich and provide food for the growth of phytoplankton.

Heat Flow in the Atmosphere

The Earth's climate is governed by a balance between the sun's energy that reaches the Earth and heat that is radiated back into space. But other factors complicate this apparently simple picture, in particular water vapor and clouds. Water vapor is the dominant greenhouse gas in the atmosphere. It traps heat radiation that would otherwise escape into space. Clouds can either reflect solar radiation back to space or absorb heat radiation.

As a result, scientists cannot understand the radiation balance without detailed information about clouds and the greenhouse effect of water vapor. CERES will, for the first time, collect information about clouds, water vapor, and radiation simultaneously. Scientists will use the CERES data to improve their predictions about the effects of global warming on the Earth's climate and to help distinguish between natural and human-induced climate changes.

Radiation measurements from CERES will be carefully matched to detailed cloud information from MODIS. CERES will also measure the relative contribution to the greenhouse effect of the lower troposphere (0-5 miles) and the upper troposphere (5-10 miles).

Monthly maps of radiation coming to and from the Earth will be created from the matched radiation and cloud measurements. These maps will provide a crucial check for the general circulation models that scientists use to simulate global climate and predict the effects of global warming, according to principal investigators Bruce Wielicki and Bruce Barkstrom of NASA's Langley Research Center. One of the early tests will be to see how accurately the models predict the flow of radiative energy from the equator to the poles. CERES monthly global energy maps are also one of the few measurements capable of detecting long-term changes in the Earth's climate system.

Scientists will also use the information to improve the way climate models simulate clouds. Such simulations are the biggest sources of uncertainty in general circulation models. This is because clouds can either warm or cool the atmosphere depending on their particular characteristics. Leo Donner, an atmospheric physicist from NOAA's Geophysical Fluid Dynamics Lab at Princeton University, will use CERES data to improve the mathematical description of how clouds affect radiation. He will do this by comparing the cloud and radiation data with simplified mathematical representations of clouds to look for more realistic ways to simulate clouds in the models. More realistic clouds will result in a more accurate depiction of how climate works and changes.

Atmospheric scientist David Randall of Colorado State University will also use CERES to study clouds, but he plans to do this by using the data to study the natural changes in the Earth's radiative budget. CERES will provide the first data able to compare changes in radiation with changes in cloud features such as altitude, size, and composition. These changes will provide important clues to how clouds affect climate. Since the cloud cover and the climate on the Earth vary dramatically from day to night, Randall plans to initially focus on these simple, strong, and frequent day-to-night changes.

The CERES radiative energy measurements at the top of the atmosphere will be combined with simultaneous surface measurements at sites around the world by Thomas Charlock of NASA's Langley Research Center. This will provide greatly improved measurements of the amount of solar energy absorbed in the atmosphere. Past attempts to measure this absorption have led to widely varying and puzzling results.

Atmospheric scientist V. Ramanathan of Scripps Institution of Oceanography plans to use CERES measurements to predict the effect of water vapor on the climate of a warmer Earth. Most scientists predict that water vapor will magnify the effect of global warming because warmer air can hold more moisture and a warmer planet evaporates more water. But skeptics claim that increased storm activity on a warmer planet might create a drier atmosphere, which would diminish the effect of global warming.

Ramanathan and colleagues have already used other satellite data to show that the warming effect of water vapor is enhanced in hot regions of the Earth. But a critical question for making global predictions is to determine the climate effect of water vapor in the upper troposphere. Water vapor is three times more effective at trapping heat if it is in this region than if it is at lower altitudes, said Ramanathan. CERES measurements will be used to distinguish the contribution of water vapor in the lower and upper troposphere to the total atmospheric greenhouse effect.

Snow and Ice and Floods

When warm spring days begin to melt winter snow pack in the northern United States, rivers swell and often flood the surrounding countryside. At times, the floods can be devastating. Thomas Carroll, director of the National Weather Service's National Operational Remote Sensing Center will use MODIS data to help map the extent of snow cover in the lower 48 United States. The snow cover maps will offer detailed information to help forecast spring flooding.

Carroll currently uses ground, airplane, and NOAA satellite measurements to map the amount of snow on the ground. MODIS snow cover maps will be twice as detailed, making them more valuable for this purpose. Also, MODIS will be able to better tell clouds apart from snow, something that is difficult to do currently from space. In the western United States, over 80 percent of the water supply comes from melting winter snow pack. Knowing the amount of snow cover is important for predicting how much water will be available for agriculture, fish habitats, drinking water, and recreation.

By monitoring global snow cover, MODIS will also give climate modelers a critical piece of information about how the amount of snow and ice on the Earth affects the climate. Colorado State University atmospheric scientist Glen Liston will use MODIS data to improve global and regional climate prediction models. When the sun shines on white snow and ice surfaces, most of the radiation is reflected back to space. Areas covered by snow cannot heat up the atmosphere like areas covered by soil or other ground cover.

The ice in the Earth's polar regions constitutes a huge reservoir of fresh water that responds relatively rapidly to climate change. If ice in the Greenland or Antarctic caps were to flow more quickly into the ocean, sea levels could rise dramatically. Fresh water from melting ice added to the salty ocean could also change the density of the ocean surface water and thereby change ocean circulation, a major component of the Earth's climate system.

Ted Scambos and Anne Nolin, glaciologists from the National Snow and Ice Data Center at the University of Colorado, will use MODIS to monitor the way that ice in

Greenland and Antarctica is behaving, both for changes in ice flow patterns and changes in the extent of melting each summer. Because MODIS collects more types of radiation data, it is twice as sensitive to different shades of gray that define features like ridges and crevasses on the white ice than instruments currently used to map the ice sheets.

MODIS data will also be used to monitor changes along the Antarctica Peninsula. Ice in the Antarctica Peninsula is responding to a warmer climate more rapidly than in other parts of the Antarctic Ice Sheet, making it a very important area for future study.

Urbanization and Agriculture

Changing the Earth's natural ground cover can alter everything from large-scale weather patterns to the smallest ecosystems. The amount of heat coming off the ground changes with different types and colors of surfaces. With ASTER, heat coming off the ground can be measured from space more accurately than any previous civilian satellite sensor. Knowing the temperature of the ground can also tell scientists how much water is in the soil, an important fact for farmers and land managers.

The Earth's surface has been paved and ploughed, watered and mowed, and topped with all types of ground cover, each with a different way of holding in the sun's radiation and reflecting it back. With all these man-made surfaces changing the way the Earth would normally deal with the sun's heat, it's important to know how high the temperatures rise and what the added heat will do.

Researchers will use ASTER along with data from Landsat satellites to study "heat islands" created by North American cities including Los Angeles, Chicago, Atlanta, Washington, D.C., Phoenix, Salt Lake City, Sacramento, Tucson, Baltimore, and Baton Rouge.

Unlike data currently available from Landsat satellites, ASTER can be used to tell different surfaces from one another because it will provide more than one type of thermal remote-sensing data. Dale Quattrochi and Jeff Luvall, remote-sensing scientists from NASA's Marshall Space Flight Center, plan to use data collected four times a year to compare how urban landscapes control the heat island effect.

Away from sprawling urban areas, rural and agricultural regions will also benefit from ASTER's heat-sensing capability. University of Arizona hydrologist Jim Shuttleworth said that by knowing the temperature of plants, scientists can tell if crops and natural vegetation are short of water.

Obviously, moisture in the soil is a major factor affecting how plants grow. By monitoring the temperature of plants, scientists can indirectly tell if there is enough moisture in the soil. Shuttleworth will use ASTER data for studies in several different types of climates, including semi-arid regions in the southwest United States, moist areas in the Tennessee Valley, and the Amazon rainforest of Brazil. In the Southwest, it is important for ranchers to know where soil is moist enough to produce pasture for livestock to feed on. Knowing how much moisture is in the soil can help predict flooding in the Tennessee Valley and elsewhere in the United States, as well as help farmers decide where and when to water their crops. And in the Amazon rainforest, the surface temperature can help scientists understand how changing the vegetation from forest to cropland affects regional and global climate.

Long-term Ecosystem Changes

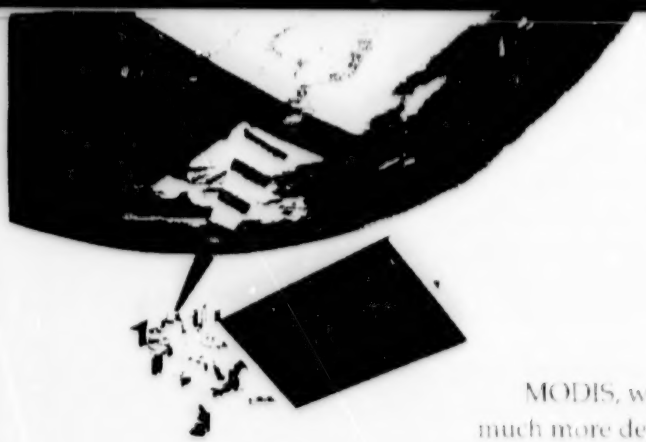
By combining information from three Terra sensors, scientists will be able to see subtle changes in forest ecosystems with the changing seasons. And by using a comprehensive 20-year collection of satellite data along with new MODIS data, scientists will decipher long-term changes to global ecosystems, providing a global check of the planet's vitality.

David Schimel, an ecosystem scientist from the National Center for Atmospheric Research, will combine data from Landsat and the Terra sensors MODIS, MISR, and ASTER to look at how growing seasons in the Northern Hemisphere are responding to overall global temperature and rainfall trends.

Keeping track of the beginning and end of the growing season is difficult for satellites. As snow melts in the spring, it is hard to determine whether the ground is covered by vegetation. In the fall, as leaves die but still cling to trees, it is hard to see exactly when the growing season ends. Schimel will study seasonal changes in North America, including Alaska, and northern China.

A regional study by University of Arizona hydrologist Soroosh Sorooshian will use MODIS data to keep track of seasonal land cover changes in the Southern Colorado Basin. Sorooshian will study whether seasonal changes in vegetation growth are connected to large climate events like El Niño. Knowing how larger and smaller climate systems are related could help scientists forecast drought events and evaluate forest fire hazards.

NASA Goddard biologist Compton Tucker and his team will add MODIS data to nearly two decades of NOAA satellite observations, continuing their long-term studies of global vegetation cover and the expansion and contraction of the world's major deserts. MODIS data will be combined with the historical record of data to determine how land vegetation varies from year to year.



MODIS, with twice the spatial resolution of previous instruments, will collect much more detailed vegetation information. MODIS is also more sensitive to different types of radiation reflected by the Earth's surface, helping the sensor see vegetation more clearly. This is important in arid and semi-arid environments where green vegetation can be sparse.

Evaluating dry desert environments is important for understanding climate stability, changes in vegetation cover over time, and identifying specific areas of desertification. MODIS data can also be used to map year-to-year variations of desert margins, areas responsible for adding dust to the atmosphere that affects climate by blocking sunlight. The dust contains iron particles that travel through the atmosphere and eventually settle into the ocean. With MODIS, scientists can track the iron-rich dust that acts as a fertilizer promoting the growth of microscopic marine plants.

The same information used for studying variations in African desert margins is used to warn of oncoming famine. Tucker and his team will use the near real-time data to identify drought regions, map the affected areas, and understand current climate conditions for all of Africa. The information is shared with the U. S. Agency for International Development's Famine Early Warning System and provided to groups working throughout Africa on famine mitigation.

Health of the Ocean's Plant Life

Half of all carbon dioxide absorbed by plants on Earth takes place in the oceans. Microscopic phytoplankton use carbon dioxide during photosynthesis, making the single-cell plants a major part of the global carbon cycle. Scientists will use MODIS to understand how this massive stock of plant life regulates the amount of greenhouse gases in the Earth's atmosphere. The amount, distribution, and health of phytoplankton can also tell scientists and fishermen which areas of the ocean contain larger fish and marine mammals. MODIS will be able to monitor the quantity of phytoplankton and determine the health of the plants.

Kevin Arrigo, an oceanographer of Stanford University, will use MODIS to study the Southern Ocean around Antarctica. Because of its remote location, satellites are the best way for scientists to study seasonal phytoplankton blooms in the ocean surrounding the frozen continent. Satellite sensors can see microscopic phytoplankton in the oceans by detecting chlorophyll in the plants. Millions of phytoplankton "bloom" and tint the blue ocean a bright green. In 1994, using data from NASA's Nimbus 7 satellite, Arrigo found that phytoplankton blooms happen much earlier in the season than scientists previously thought.

Arrigo hopes to distinguish between different types of phytoplankton using the greater sensitivity MODIS has to different types of radiation. Each type of phytoplankton

contains different pigments and, therefore, show up as a different shade of green. Arrigo believes it is important for scientists to take into account the behavior of different phytoplankton types because they all have different effects on global climate. They consume carbon dioxide at different rates, and in some cases produce gases that turn into aerosols in the atmosphere.

Eileen Hofmann, an oceanographer at Old Dominion University, will use MODIS to study phytoplankton in the equatorial Pacific Ocean. Because the region is so large, it has an important potential role in the global carbon cycle. The equatorial Pacific contains plenty of nutrients for phytoplankton, so scientists expect to see large blooms of the microscopic plants. However, satellite images do not show large amounts of chlorophyll, the tell-tale sign of phytoplankton blooms. Hofmann will use MODIS data with mathematical models to determine whether the lack of phytoplankton is due to biological factors, such as a lack of the nutrient iron in the equatorial Pacific, or physical factors, such as a change in ocean circulation.

John Walsh, a marine scientist at the University of South Florida, will compare MODIS data to models of phytoplankton behavior in the Caribbean and the West Florida Shelf, where there are large amounts of the microscopic plants. Walsh uses models to predict how populations of four to five different species of phytoplankton interact. There is some difficulty measuring phytoplankton amounts with spacecraft sensors because dead plants also show up green in the satellite images. The radiation sensitivity of MODIS will help differentiate the live plants from the dead and give more accurate measurements of total phytoplankton amounts.

Mark Abbott, an Oregon State University oceanographer, said that in addition to finding out how much phytoplankton there is, it is also important to know how healthy the phytoplankton are. Phytoplankton absorb sunlight and either use it to grow or re-emit it as faint, red fluorescence. A lot of fluorescence coming from an area in the ocean is a sign of unhealthy phytoplankton populations, said Abbott. MODIS is the first satellite sensor that can see fluorescence from the phytoplankton blooms. Abbott plans to use MODIS to check on phytoplankton health in studies of the Pacific Ocean north of Hawaii and along the California and Oregon coasts.

An Elusive Greenhouse Gas

Methane, one of the major greenhouse gases, is produced by both natural processes and human activities. Scientists know that methane is produced in large quantities by wetlands in northern Canada and Siberia, fossil fuel extraction, rice cultivation, landfills, and herds of cattle and other livestock. But lacking is such basic information as how large these sources are and where they are. Researchers will use MOPITT data to answer these basic questions.

MOPITT will produce maps of methane concentrations in the lowest 10 miles of the atmosphere over the entire globe. Methane levels in the Earth's atmosphere are low – a few molecules in a million – but the gas makes a sizable contribution to global warming, second only to that of carbon dioxide despite its much lower concentration. These will be the first global maps of an important chemical that is produced by biological as well as man-made sources. The measurements will enable scientists to dramatically improve estimates of methane emissions. Determining the biggest sources will focus attention on how to control methane emissions. Methane is one of the greenhouse gases listed in the Kyoto Protocol.

Producing methane maps with enough detail to pinpoint the sources and sinks is a daunting task. Although methane is produced by distinct regional sources, methane in the atmosphere is fairly homogeneous. The biggest natural variation only amounts to a few percent difference. To reveal these small differences, MOPITT will have to make very precise measurements.

Current estimates for methane sources and sinks are based on extrapolation from a few well-studied field sites, said atmospheric scientist Inez Fung at the University of California, Berkeley, who is responsible for some of the most widely used estimates. She plans to use MOPITT data to improve our understanding of methane sources. For example, current estimates lump emissions from all wetlands together. She will use the data to look for major differences between emissions from wetlands in northern Canada and Siberia. She will also determine whether different methods of rice cultivation and landfilling produce different amounts of methane.

Although methane is the most rapidly increasing greenhouse gas – concentrations have more than doubled since the late 1700s – scientists do not have good explanations for the increase. They also cannot explain why the growth in atmospheric methane has slowed over the last decade.

Atmospheric scientist David Schimel at the National Center for Atmospheric Research plans to study how natural processes in the atmosphere control methane concentrations. He will compare MOPITT methane data from different years to study large-scale patterns in climate to get a fix on what natural processes in the atmosphere control methane concentrations. For example, methane concentrations dropped dramatically after the eruption of Mt. Pinatubo in 1991, but the causes, which may be linked to the global cooling that followed the volcanic eruption, remain a subject of active research. Hopefully, MOPITT will be able to observe similar natural variations in climate and methane and provide clues to how methane levels may change in the future.

A Key Carbon-Consuming Marine Plant

Scientists believe that one of the culprits in the "missing carbon" problem – the discrepancy between known sources of atmospheric carbon and known sinks – may be tiny microscopic plants called coccolithophores. All microscopic plants in the ocean live on carbon dioxide. But coccolithophores are the only one-celled plants that take bicarbonate—a molecule containing carbon—and turn it into fancy microscopic exoskeletons (resembling doilies) made of calcium carbonate, or limestone.

The plants coat themselves in an armor of the limestone discs called coccoliths. When the plants die, the coccoliths and the carbon they contain can fall to the ocean floor and build up over millions of years into thick beds of limestone. The result is the removal of carbon from the Earth's atmosphere-ocean system. MODIS will provide the first remote-sensing data designed to keep track of the carbon dioxide-consuming coccolithophores.

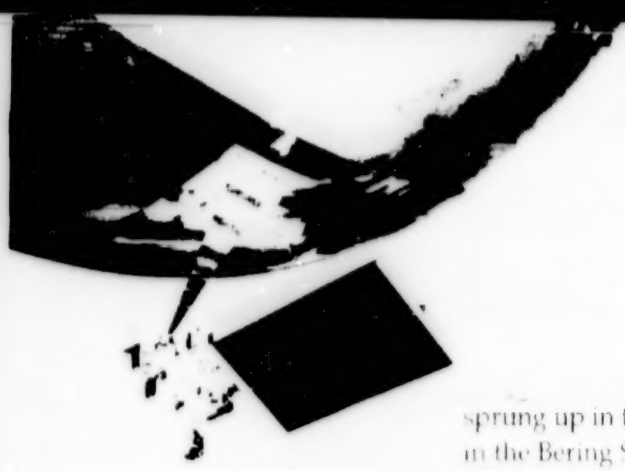
Under the right conditions, coccolithophores produce massive "blooms" containing billions of individual microscopic plants that can cover an area of ocean the size of England. The coccolith discs covering the microscopic plants act like tiny mirrors, reflecting a large amount of solar radiation.

William Balch, a marine biologist from the Bigelow Laboratory in Maine, said that these large blooms can cause the ocean surface to reflect 30 times more sunlight than usual, turning the dark blue ocean a vibrant aquamarine. The way that coccoliths reflect sunlight makes it possible for satellite instruments to precisely measure the amount and distribution of coccolithophore blooms.

Although satellites can see phytoplankton in the oceans because chlorophyll in the microscopic plants turn the ocean green, it has not been possible to tell one species of phytoplankton from another from space, except in the case of coccolithophores. Balch said that coccoliths have been a problem for remote sensing because their presence makes it more difficult to measure how much chlorophyll the ocean contains, and therefore how much total phytoplankton is blooming. Even when the coccolithophores are not in full bloom, they account for about 10 percent of the back-scattered light reaching satellites, making chlorophyll measurements less accurate.

Balch said that the amount of carbon coccolithophores take out of the ocean-atmosphere system is about equal to the carbon released from human agricultural activities, but less than the amount of carbon in carbon dioxide created by burning fossil fuels.

MODIS will help researchers study the Bering Sea, part of the northern Pacific Ocean surrounding Alaska where massive coccolithophore blooms have unexpectedly



sprung up in the past few years. Researchers had never observed such large blooms in the Bering Sea before. Some scientists think that these blooms are part of larger changes in the surrounding ecosystem. The bloom's presence coincided with lower salmon counts along the coasts, a redistribution of microscopic animals in the surrounding ocean, and deaths of surface-feeding seabirds.

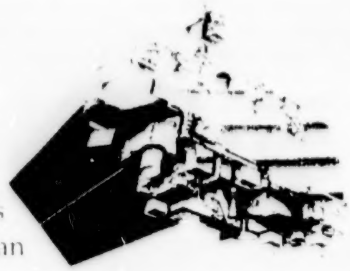
The Cooling Effect of Airborne Aerosols

Forest fires, volcanic eruptions, dust storms, smoke stacks, and sea spray all act to loft tiny particles into the Earth's atmosphere, where they influence how much solar energy warms the planet. Scientists estimate that the global effect of this hodge-podge of aerosol particles is to cool the planet because aerosols generally scatter incoming solar radiation back into space. Aerosols are also believed to affect the brightness and longevity of clouds, possibly increasing their ability to reflect sunlight away from the Earth. Whether that cooling effect is small or large is one of the largest remaining unknowns in the ongoing debate over future global warming.

Satellite instruments have demonstrated that it is possible to routinely estimate the amount of aerosol in the atmosphere over vast areas of dark ocean. But the current generation of satellite remote-sensing instruments were not designed for aerosol studies, and they do not collect the information needed to distinguish different types of aerosols or to estimate aerosol amount over brighter and more complex land surfaces. MISR and MODIS will provide improved global measurements of aerosol amount, and each instrument will give some indication of particle properties that can be used to identify the source and evolution of the particles.

Pre-launch simulations of MISR data suggest that under good viewing conditions MISR will be able to classify aerosols into about a dozen different types, based on size, shape, and compositional differences. This new capability arises mainly because a particle's physical properties affect the way it scatters sunlight at different angles. MISR will observe at nine different angles, each at four wavelengths, a measurement capability never before available. MISR is also expected to detect aerosol amount over some types of land, using the multi-angle data to help distinguish light scattered by airborne particles from that reflected by the underlying surface.

Since MISR will obtain global coverage about every 9 days and clouds will sometimes block the instrument's view of aerosols, MISR will produce global maps of aerosols from available observations on a monthly basis, according to atmospheric scientist John Martonchik at NASA's Jet Propulsion Laboratory. MODIS, with global coverage every 1-2 days, will provide complementary data. These Terra data sets will track such regional events as dust from the Sahara Desert, forest fire and volcanic particle plumes, and aerosol emissions from industrial sites in northern Europe and the United States.



Climate modeler Steven Ghan at the Battelle Pacific Northwest Laboratory plans to use MISR data to improve predictions of the global climate effects of aerosols. Ghan uses computer models to simulate the effects of industrial sulfate aerosols. Using meteorological data and sparse data on sources of aerosols such as industrial fuel consumption and biomass burning, the models simulate the complex transformations and motions of aerosols through the atmosphere to produce predictions of where aerosols come from and how much they change a region's climate. By comparing these model predictions to MISR's real-world observations, Ghan hopes to improve his estimates and differentiate the role of man-made aerosols on climate from natural aerosols.

Atmospheric chemist Stephen Schwartz at the U.S. Department of Energy's Brookhaven National Laboratory has modeled how aerosols form from sulfur gases and move from North America toward Europe. Schwartz plans to use MISR aerosol data to test how well his model simulates aerosol formation and transformation across an entire hemisphere (north and south). These are complicated processes because aerosols, unlike greenhouse gases in the atmosphere, are not distributed evenly throughout the atmosphere and vary greatly in chemical and physical properties.

NASA's Earth Observing System

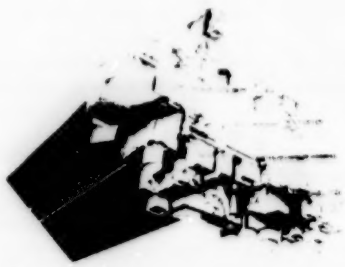
The purpose of NASA's Earth Science Enterprise is to understand the total Earth system and the effects of natural and human-induced changes on the global environment. The Office of Earth Science is pioneering the new interdisciplinary field of research called Earth system science, born of the recognition that the Earth's land surface, oceans, atmosphere, ice sheets and biota are dynamic and highly interactive.

The Office of Earth Science is comprised of an integrated slate of spacecraft and in situ measurement capabilities; data and information management systems to acquire, process, archive, and distribute global data sets; and research and analysis projects to convert data into new knowledge of the Earth system. The office is NASA's contribution to the U. S. Global Change Research Program, an interagency effort to understand the processes and patterns of global change.

The centerpiece of the Earth Science Enterprise – the Earth Observing System (EOS), established in 1991 – is a program of multiple spacecraft and interdisciplinary science investigations to provide key information needed to understand global climate change. The Terra satellite (formerly EOS AM-1) will provide measurements that will significantly contribute to our understanding of the Earth system. Several spacecraft and instruments are scheduled to fly as part of the EOS program in the next few years.

The overall goal of the EOS program is to advance the understanding of the entire Earth system on a global scale by improving our knowledge of the components of the system, the interactions between them, and how the Earth system is changing. The EOS program mission goals are to (1) create an integrated, scientific observing system emphasizing climate change that enables multi-disciplinary study of the Earth's critical, interrelated processes; (2) develop a comprehensive data information system, including a data retrieval and processing system; (3) serve the needs of scientists performing an integrated multi-disciplinary study of planet Earth; and (4) acquire and assemble a global database of remote-sensing measurements from space over a decade or more to enable definitive and conclusive studies of the Earth system.

The three main EOS spacecraft that will support a broad range of scientific investigations instruments are Terra, EOS PM, and EOS Chemistry. Beginning in 1999, 2000, and 2002 respectively, each of the satellites will be flown for a period of at least six years. Additional observations will be provided by Landsat 7, launched in April 1999, and several other missions.



Nearly all U.S.-led EOS missions include international contributions. For example, Terra will fly an instrument from Canada (Measurements of Pollution in the Troposphere, MOPITT) and one from Japan (Advanced Spaceborne Thermal Emission and Reflection Radiometer, ASTER). The EOS PM mission will include the Japanese Advanced Microwave Scanning Radiometer (AMSR-E) instrument and the Humidity Sounder for Brazil (HSB). Several U.S. instruments are scheduled to orbit aboard satellites launched by other countries, including the Russian Meteor 3M-1, Japanese ADEOS II, and the French Jason-1 spacecraft. In addition, numerous agreements have been signed for joint data exchange and distribution, including cooperation in EOSDIS.

EOS sponsors many interdisciplinary research investigations that use specific Earth science data sets for a broader investigation into the function of Earth systems. Current EOS research spans a wide range of sciences, including atmospheric chemistry, hydrology, land use, and marine ecosystems.

The EOS Project Science Office at Goddard Space Flight Center consists of the Senior Project Scientist as well as Project Scientists associated with the various EOS payloads and the EOSDIS. This office serves as the primary day-to-day interface between the Earth science community and the EOS projects at all NASA centers.

Complementing the EOS missions is a series of small, rapid development Earth System Science Pathfinder missions to study emerging science questions and to use innovative measurement techniques in support of EOS. The New Millennium Program is designed to identify, develop, and validate key instrument and spacecraft technologies that can enable new or more cost-effective approaches to conducting science missions in the 21st century.

Data from past and current Earth science missions are captured, processed into useful information, and broadly distributed by the EOS Data and Information System. In addition to EOSDIS, NASA is engaging in a variety of activities to extend the usefulness of Earth science data to a broad range of users such as Regional Earth Science Applications Centers.

The intellectual capital behind Earth science missions, and the key to generating new knowledge from them, is vested in an active program of research and analysis. Over 1,500 scientific research tasks are funded by the Earth Science Research and Analysis program.

EOS Spacecraft and Instruments

ACRIMSAT is a small satellite dedicated to the Active Cavity Radiometer Irradiance Monitor III (ACRIM III) instrument. ACRIM III provides long-term, precise measurements of the total amount of the sun's energy that falls on the Earth. Launch is scheduled for November 1999.

Advanced Earth Observing Satellite II (ADEOS II) is a joint mission with the National Space Development Agency of Japan. The SeaWinds microwave radar on this mission will collect all-weather measurements of surface wind speed and direction over the global oceans. Launch is scheduled for November 2001.

EOS Chemistry will focus on measurements of atmospheric trace gases and their transformations. This mission will provide the first global measurements of several important tropospheric chemicals, as well as continuing critical measurements of the upper troposphere and lower stratosphere that affect ozone concentration in the Earth's atmosphere. Launch is scheduled for December 2002.

EOS PM, the second large spacecraft in the EOS series, will fly in a polar, sun-synchronous orbit with an afternoon (1:30 p.m.) equatorial crossing time. PM will carry two instruments that are also on Terra (CERES and MODIS), as well as two new instruments. Launch is scheduled for December 2000.

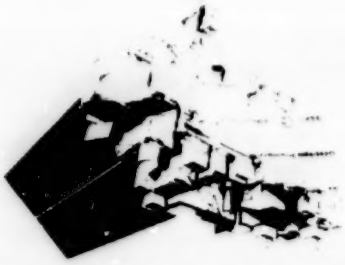
Ice, Cloud and land Elevation Satellite (ICESat) is a small satellite mission to fly the Geoscience Laser Altimeter System (GLAS) to accurately measure the elevation of the Earth's ice sheets, clouds, and land. Launch is scheduled for July 2001.

Jason-1 is a joint U.S.-France oceanography mission designed to monitor the topography of the global oceans that determine ocean circulation, probe the connection between the oceans and atmosphere, and improve global climate predictions. Launch is scheduled for May 2000.

Landsat 7 is providing a unique suite of high-resolution observations of the terrestrial environment for global change research, regional environmental change studies, and other civilian and commercial purposes. Launched April 15, 1999.

Meteor 3M-1 is a small Russion spacecraft that will carry the Stratospheric Aerosol and Gas Experiment III (SAGE III) instrument that will make long-term trend measurements of atmospheric aerosols, ozone, water vapor, and clouds. Launch is scheduled for summer 2000. SAGE III will also be mounted on the International Space Station in 2003.

QuikScat. The SeaWinds instrument on the QuikScat mission is a specialized microwave radar that measures near-surface wind speed and direction under all weather and cloud conditions over the Earth's oceans. Launched June 19, 1999.



Solar Radiation and Climate Experiment (SORCE) will provide long-term, accurate measurements of the sun's solar irradiance from the ultraviolet to near-infrared wavelengths as well as the sun's total solar irradiance. Launch is scheduled for July 2002.

Terra will observe the Earth's continents, oceans, and atmosphere with five state-of-the-art instruments achieving measurement capability and accuracy never flown in space before. Launch is scheduled for late 1999.

Other NASA Earth Science Missions

CloudSat. CloudSat's primary goal is to furnish data needed to evaluate and improve the way clouds are represented in global climate models, thereby contributing to better predictions of clouds and their poorly understood role in climate change. Launch is scheduled for April 2003.

Earth Observing 1. The New Millennium Program's first earth science flight, EO-1 will validate technologies contributing to the reduction in cost of follow-on Landsat missions. Launch is scheduled for December 1999.

Gravity Recovery and Climate Experiment. The second of the Earth System Science Pathfinder (ESSP) missions, GRACE employs a satellite-to-satellite microwave tracking system between two spacecraft to measure the Earth's gravity field and its time variability over five years. Launch is scheduled for June 2001.

PICASSO-CENA. The Pathfinder Instruments for Cloud and Aerosol Spaceborne Observations – Climatologie Etendue des Nuages et des Aerosols (PICASSO-CENA) mission, is a joint mission lead by NASA's Langley Research Center and the Institut Pierre Simon Laplace, Paris. PICASSO-CENA flies in formation with EOS PM and CloudSat to provide global observations of aerosol and cloud properties, radiative fluxes, and atmospheric state. Launch is scheduled for April 2003.

QuikTOMS. The Total Ozone Mapping Spectrometer (TOMS) continues NASA's long term mapping of the global distribution of the Earth's atmospheric ozone. In addition to ozone, TOMS measures sulfur-dioxide released in volcanic eruptions. Launch is scheduled for September 2000.

Triana. The Triana spacecraft is designed to obtain daily global images of ozone, aerosols, water vapor, cloud cover, cloud height, and vegetation information. These images will be from sunrise to sunset for every point on the globe at a spatial resolution of about 8 km. Launch is scheduled for December 2000.

Vegetation Canopy Lidar. The first of the ESSP missions, VCL seeks to provide the first global inventory of the vertical structure of the Earth's forests using a multi beam laser-ranging instrument. Launch is scheduled for September 2000.

Information Resources

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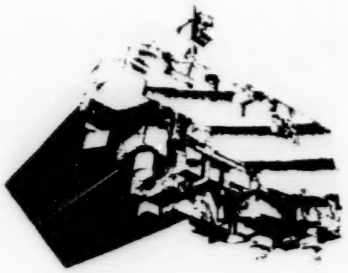
World Wide Web Sites

Terra (http://terra.nasa.gov/)
The Terra site provides images, animations, and background information about the mission. The site contains detailed information about Terra's payload of sensors and its science objectives. There are also links to instrument team sites and data archive centers.

Terra Instrument Team Sites
ASTER (http://asterweb.jpl.nasa.gov/)
CERES (http://asd-www.larc.nasa.gov/ceres/ASDceres.html)
MISR (http://www-misr.jpl.nasa.gov/)
MODIS (http://modarch.gsfc.nasa.gov/MODIS/)
MOPITT (http://www.atmosp.physics.utoronto.ca/MOPITT/home.html)

EOS Project Science Office (http://eospso.gsfc.nasa.gov/)
The EOS Project Science Office at Goddard Space Flight Center maintains an active Web site that is a good source for the latest news and detailed background information on the entire EOS program. The site includes regularly updated listings of EOS spacecraft, instruments, research projects, and the associated personnel. In addition, the site provides extensive links to NASA centers, image archives, documents, and educational materials.



Destination Earth (http://www.earth.nasa.gov/)
The Web site of NASA's Earth Science Enterprise in Washington, D. C., contains information about the Agency's entire Earth science program. "Science of the Earth System" describes the Agency's major research themes: atmospheric chemistry, hydrological and energy cycle, land cover and land use, ozone, natural hazards and the solid Earth, and climate variability and change. "Missions" provides links to all major spacecraft missions and instruments as well as the Earth Probes program, the New Millennium missions, and commercial remote sensing.

Earth Observatory (http://earthobservatory.nasa.gov)
The Earth Observatory presents articles, images, and animations that illustrate the complexities of Earth system science as well as NASA's use of satellites and remote-sensing data. The site features actual remote-sensing data of key phenomena of change on global and regional scales. Updated weekly, the Earth Observatory is an information resource for educators, interested lay persons, and media writers.

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